

High Strain-Rate and Temperature Effects on the Response of Composites

NASA John H. Glenn Research Center
Start Date: 03-01-2003, End Date: 02-28-2004
Grant/Contract No. NCC3-1027
The Ohio State University RF Project No. 744258

Final Report

May, 2004

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1. BACKGROUND

The objective of the research is to expand the experimental study of the effect of strain rate on mechanical response (deformation and failure) of epoxy resins and carbon fibers/epoxy matrix composites, to include elevated temperature tests. The experimental data provide the information needed for NASA scientists for the development of a nonlinear, strain rate and temperature dependent deformation and strength models for composites that can subsequently be used in design. This year effort was directed into the development and testing of the epoxy resin at elevated temperatures. Two types of epoxy resins were tested in shear at high strain rates of about 700 s^{-1} and elevated temperatures of 50 and 80°C . The results show that the temperature significantly affects the response of epoxy.

2. EXPERIMENTAL SETUP

Torsion tests were conducted at strain rates of approximately 700 s^{-1} using a torsional Split Hopkinson Bar apparatus (SHB). The split Hopkinson bar apparatus, shown schematically in Fig. 1, is made up of two aluminum bars. The specimen is placed (cemented) between the bars. The specimen is loaded by a wave that is generated in the incident bar by clamping a torque in the end section of the incident bar, and then releasing the clamp. Upon loading of the specimen, part of the loading wave reflects back to the incident bar, and part propagates on through the specimen to the transmitter bar. The incident and transmitter bars remain elastic throughout the test. The history of stress and strain in the specimen is determined from the recorded elastic waves in the bars. The technique was modified for testing at elevated temperatures by placing a small chamber around the specimen and blowing hot air into the chamber.

The specimen is a short thin-walled tube. It is made by machining a notch in a thick-walled tube. The thick-walled tube is made from an epoxy plate such that the axis of the tube is perpendicular to the plate. The specimen is glued to adapters that are then attached (glued) to the testing machine. The specimen and adapters are shown in Fig. 2. To examine the effect of thickness of the specimen on the results, specimens with wall thickness of 0.025 and 0.050 in. were tested.

The temperature of the specimen was measured with two thermocouples that were imbedded in the glue between the specimen to the adapters. The thermocouples are placed very close to the ends of the gage section and it is assumed that the specimen gage is at the same temperature.

4. RESULTS

Tests were conducted with specimens made of E-862, PR-520 resin materials. The tests are summarized in tables 1. For each test, the stress, strain, and strain rate (in the split Hopkinson bar tests), all as a function of time, and the stress-strain curve for the test are given in the Appendix (in the order listed in table 1).

Stress-strain curves from all the tests are presented in Figures 3 and 4, for the E-862 and PR-520 epoxies, respectively. The figures include also stress-strain curves from previous tests conducted at room temperature. The results show that the temperature has a very significant effect on the material response. For the E-862 epoxy (Figure 3) the maximum stress reduces by 25% from 80 MPa to 60 MPa as the temp increases from room temperature to 50°C, and by close to 40% as the temperature increases to 80 °C. A significant reduction is also observed in the slope in the initial portion of curves. The effects of temperature on the PR-520 epoxy (which, in general stronger than the E-862 epoxy) are similar (see Figure 4). The results from tests with specimens with different wall thickness are the same.

Table 1: Summary of 2003 Tests.

TEST NO.	SPECIMEN'S MATERIAL	STRAIN RATE (1/s)	COMMENTS
EXP03-13	Epoxy resin PR-520		Torsion, T=50°C, Glue in the gage section.
EXP03-14	Epoxy resin E-862	700	Torsion, T=50°C
EXP03-15	Epoxy resin E-862	800	Torsion, T=80°C
EXP03-16	Epoxy resin PR-520	600	Torsion, T=50°C
EXP03-17	Epoxy resin PR-520	700	Torsion, T=80°C
EXP03-18	Epoxy resin E-862	700	Torsion, T=50°C
EXP03-19	Epoxy resin PR-520	750	Torsion, T=50°C
EXP03-20	Epoxy resin E-862	750	Torsion, T=80°C, Crack in the specimen before test.
EXP03-21	Epoxy resin PR-520	750	Torsion, T=80°C
EXP03-22	Epoxy resin E-862	700	Torsion, T=80°C
EXP03-23	Epoxy resin PR-520	750	Torsion, T=80°C

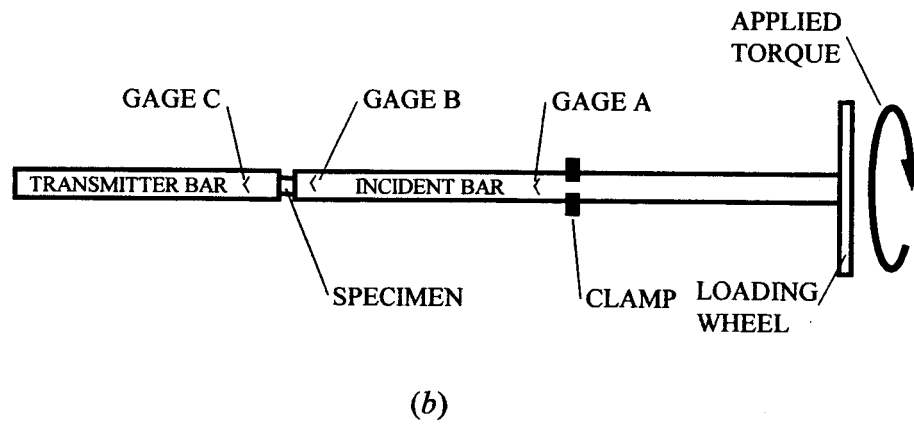
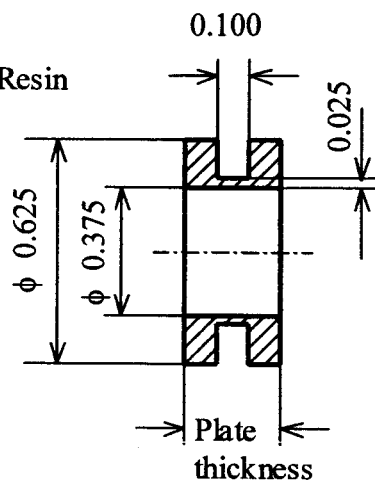
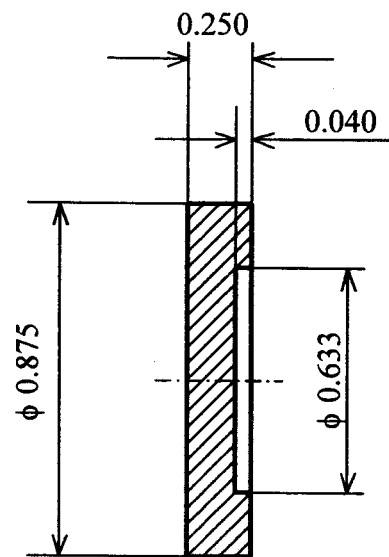


Fig. 1: Schematic of the torsional split Hopkinson bar apparatus,

Specimen
Material: Resin



(a)



Adapter, (two for each specimen)
Material: Aluminum

(b)

All dimensions are in inches.

Fig. 2: Torsion test specimen and adapters.
(a) specimen, (b) adapter

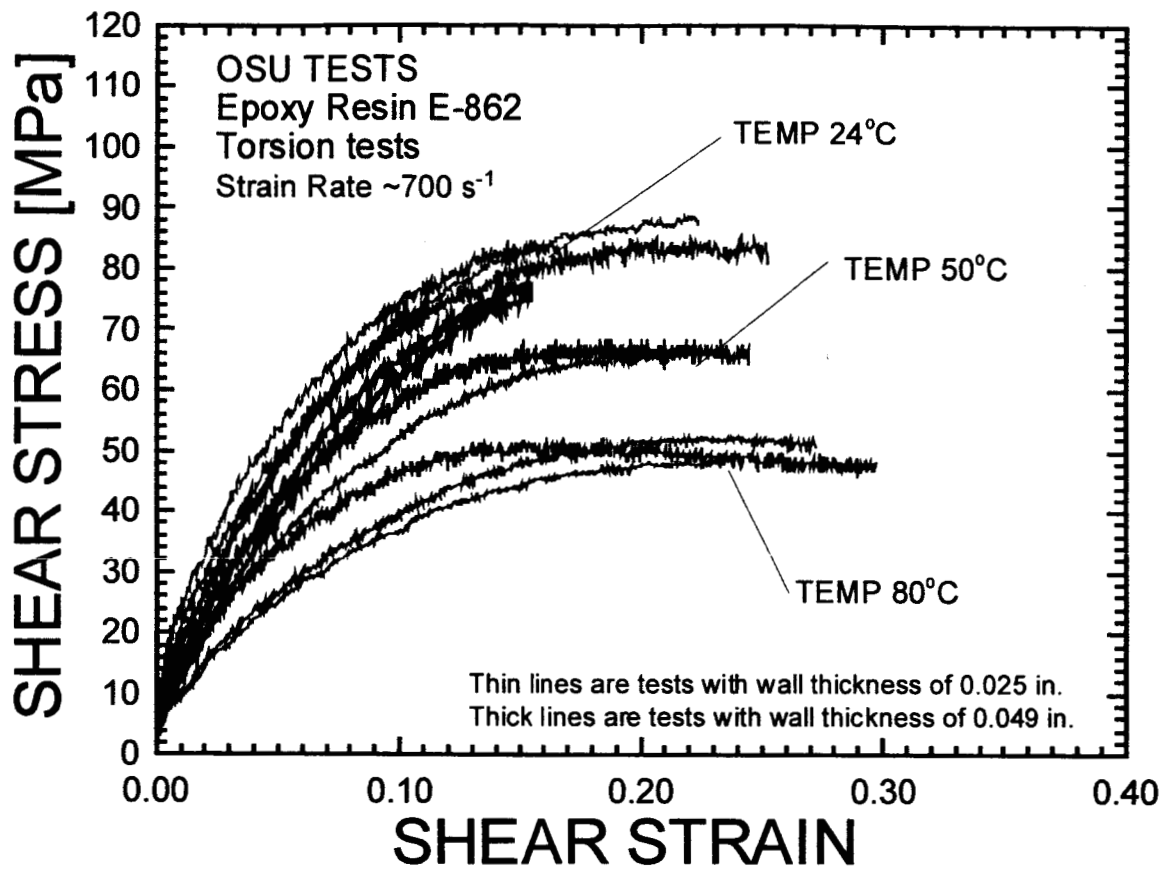


Fig. 3: Shear stress strain curves for E-862 epoxy at high strain rate and various temperatures.

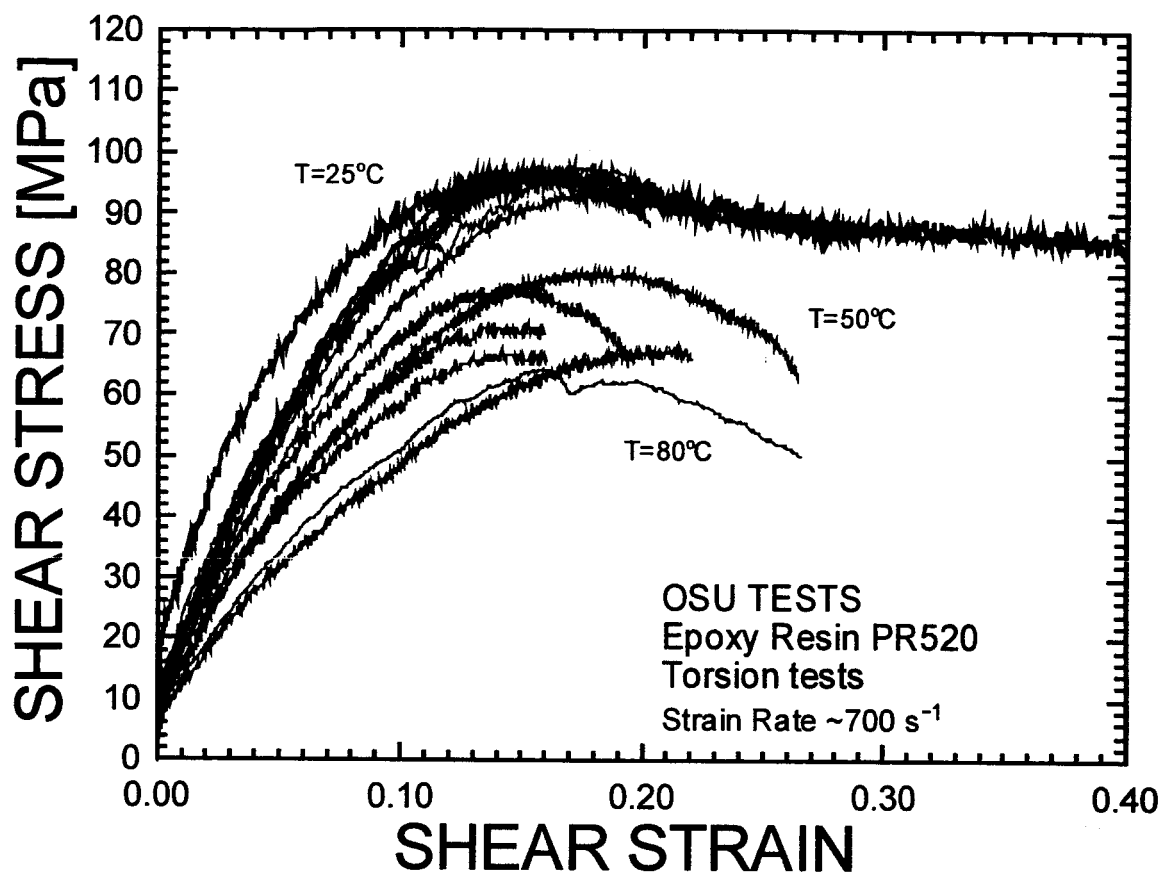


Fig. 4: Tensile stress strain curves for E-862 epoxy at high strain rate and various temperatures.

APPENDIX

For each test two plots are presented. In the first (top) plot the stress, strain, and strain rate are plotted as a function of time. The second (bottom) plot shows the stress-strain curve for the test.

The plots are in the order listed in Table 1.

